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EDITED AND REVIEWED BY
Michalis F. Vassiliou,
ETH Zürich, Switzerland

*CORRESPONDENCE
Michele Palermo,
✉ michele.palermo7@unibo.it

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Editorial: Energy dissipation devices and vibration-control systems for structures and infrastructures to mitigate damages under different hazards

Michele Palermo[1]*, Felice Carlo Ponzo[2], Dora Foti[3], Fabio Mazza[4], Izuru Takewaki[5] and Paolo Castaldo[6]

[1]Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, Bologna, Italy, [2]School of Engineering, University of Basilicata, Potenza, Basilicata, Italy, [3]Department of Civil Engineering and Architecture, Politecnico di Bari, Bari, Puglia, Italy, [4]Department of Civil Engineering, University of Calabria, Cosenza, Calabria, Italy, [5]Department of Architecture and Architectural Engineering, Kyoto University, Kyoto, Japan, [6]Department of Structural, Geotechnical and Building Engineering, Polytechnic University of Turin, Turin, Piedmont, Italy

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Editorial on the Research Topic
Energy dissipation devices and vibration-control systems for structures and infrastructures to mitigate damages under different hazards

Energy dissipation devices and vibration-control systems are increasingly being used for damage mitigation induced by earthquakes and other hazards such as strong wind, storms, hurricanes, and tsunamis that may strike structures and infrastructure. The capabilities of such devices and control systems in reducing structural vibrations, demonstrated by past hazardous events, make them particularly desirable for both new and existing strategic structures, such as police stations, schools, hospitals, and nuclear power plants and critical infrastructure, such as bridges, tunnels, and sea walls. Although some of those systems, like base-isolation systems and passive viscous dampers, are quite matured and often used in practical applications, there are still some open issues and research-related aspects deserving further investigations. On the contrary, other younger systems, such as novel energy dissipation systems, inerter-based vibration control systems, negative-stiffness vibration isolators, magneto-rheological dampers, still require further theoretical studies and experimental investigations before their full technological validation. The research contributions collected in this Research Topic deal with this topic.

The work by Nakamura and Matsumura investigates the cross-story installation of a small-size viscous damper in a timber frame house to evaluate its advantage over the conventional inter-story installation, where a damper is installed between adjacent floors. Timber frame structures are commonly used in houses that use squared-off timber beams, columns, and walls as lateral load-bearing members. Therefore, small-size viscous dampers can be used to reduce damage caused by major earthquakes. Although viscous dampers are normally installed following an inter-story placement (i.e., between two adjacent floors), another promising placemen is the cross-story installation wherein a damper is installed between the rooftop and the base of the structure across intermediate floors. The study investigated the effectiveness of cross-story installation of a viscous damper by conducting eigenvalue analyses of 2DOF models and earthquake response analyses of a two-story timber frame house subjected to the 2016 Kumamoto earthquake and other major earthquakes. The damping factors and response reduction effects of the cross-story installation were compared with those of conventional inter-story installations. The results showed that the cross-story installation of dampers was more effective than the inter-story installation in terms of reducing story drift as well as in reducing the number of dampers. Moreover, the cross-story installation allowed the viscous damper in the first story to absorb vibration energy nearly twice as much as that of the inter-story installation. Such solution may, therefore, represent a promising alternative to the more classical inter-storey damper placement as a seismic retrofitting measure.

The seismic retrofitting of existing buildings using fluid viscous dampers is also addressed by the work of Marra et al. which introduces a novel formulation to extend an existing design approach (known as the five-step procedure) for the design of fluid viscous dampers as a seismic retrofitting measure of existing frame buildings. The original design procedure, articulated into five consecutive steps, was formulated for the design of new buildings with the aim of designing the structural elements to remain within the elastic limit under a strong earthquake input. The design procedure guides the designer from the identification of the expected seismic performances, to the sizing of the added viscous dampers and the final verification of the seismic behavior through non-linear dynamic time history analyses. However, when dealing with an existing building, especially if originally designed considering vertical loads only, the insertion of viscous dampers could not be sufficient to keep the structural elements in the elastic range. Thus, it might be necessary to accept local plastic excursion of structural elements, by taking into account the ductility capacity (albeit probably limited) of structural members (hysteretic dissipation associated with damage in beams and columns). This latter aspect is explicitly considered in the updated formulation of the “direct five-step procedure” for the case of existing buildings through the introduction of an overall response reduction factor accounting for both the ductility capacity of structural members and the viscous damping provided by added dampers. The design procedure allows to carry out the sizing of viscous dampers and the estimation of internal forces in the structural members using simplified analytical formulae, while the final verifications are carried out through non-linear dynamic time history analyses. The proposed design procedure was successfully validated by investigating the seismic behaviour of an 11-storey frame structure. Three different retrofitting design strategies were compared, based on different exploitations of viscous energy dissipation provided by dampers and hysteretic energy dissipation due to the excursion of structural members into the inelastic range. The results show that the proposed design method is promising.

Added Damping and Stiffness (ADAS) steel devices are among the most classical devices installed in dissipative bracing systems for the seismic retrofit of frame buildings. An energy-based sizing procedure is formulated for this class of dampers in the study by Terenzi et al. The sizing procedure takes into account the relationship between the total number of constituting plates and the supplementary damping energy required to jointly reduce the stress level of structural members and the storey drifts. Moreover, the stiffening effects of dissipative braces are explicitly controlled in order to account for the increase in storey shears induced by their incorporation in the frame skeleton. The novelty of the procedure, as compared to other existing methods, is related to the direct (no iteration is required) evaluation of the energy demand based on simplified analytical relations making use of spectral displacement, velocity, and pseudo-acceleration ordinates. The evaluation of the seismic performance of the structure in retrofitted conditions allows comparing the response of the dissipative bracing system with the hypotheses formulated at the sizing stage. The proposed sizing procedure is validated by considering the retrofitting of a 6-storey reinforced concrete building. The use of the proposed analytical relations and their limitations for the practitioners are also discussed.

Seismic isolation, in addition to energy dissipation, is the other common design strategy adopted to mitigate the effects of the seismic input on the structural members. Among the various types of seismic isolators proposed in the litterature, the study of Di Cesare et al. investigates the behavior of double concave curved surface slider isolators with a flat rim and lacking restrainers, such as those most commonly used in Europe. It is known that the rigid slider can exceed the geometrical capability of the housing plate during earthquakes stronger than those considered in the design phase. During this over-stroke displacement, the isolators is capable to keep their ability to support superstructure gravity loads and the capacity to dissipate energy. However, there is currently neither applicable hysteresis rule nor analytical formulation that can be used to predict over-stroke behaviour for response-history analysis. The study presents a novel analytical solution to extend basic theories for estimating the actual limit displacement of the devices with over-stroke capacity. The device model was augmented with a friction model capable of accounting for torsional effects, axial load, and velocity variabilities. The proposed analytical formulation was calibrated considering the results of experimental controlled-displacement tests performed on single devices. The comparison between the non-linear numerical results (explicitly considering the dependence of the friction from the dynamic condition of velocity and axial load) and the proposed analytical solution derived from static conditions, shows that the proposed formulation is capable to accurately predict the over-stroke force and displacement. A case study of an isolated six-storey reinforced concrete frame building was then considered to further validate the proposed model. The comparison between the predictions and the outcomes of the non-linear dynamic analysis shows that the forces and displacements in the over-stroke sliding range are predictable and therefore the model can be of practical utility for practitioners.

The qualification of novel energy dissipation and isolation devices is commonly performed through experimental testing performed on dynamic shaking tables facilities. The present Research Topic ends with the work by Enokida et al. that introduces a numerically disturbed experimentation approach to address the shake table control degradation commonly observed in shake table experiments. During experimental tests this degradation is caused by nonlinear phenomena, such as damage accumulation. On the other hand, the observation of those nonlinear phenomena is the major purpose of these experiments. The work proposes a numerically disturbed experimentation, consisting in simulating the structural responses that are feedbacked as the disturbance signal to the table in the physical domain via real-time interaction. This enables to examine the control performance of a shake table with a structure, without having to place an actual structure on it. The simulated experimentation is beneficial in cases wherein new control methods are applied for shake table control. The proposed experimentation method was applied to the shake table control examination of the nonlinear signal-based control showing the capability to accurately reproduce a seismic acceleration record with severe nonlinear characteristics. Similar results were obtained using actual shake table experiments with a steel structure. It was concluded that the proposed numerically disturbed experimentation can be an alternative to real shake table experiments using structures.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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